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Improving Reinforced Concrete Column Strengthening Techniques for Reconstruction Projects Using Composite Jacketing Formworks

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Abstract: The paper looks at the issues of reconstruction of modern construction systems, in particular, the possibility of their functional repurposing. Examples from the global practice are provided to illustrate the conversion of industrial facilities for use as residential and public buildings. Based on an overview of scientific publications, the paper offers a set of rationales for the preservation of industrial facilities and highlights the benefits of reconstruction aimed at improving their residual lifespan and ensuring further reliable operation. Reconstruction is noted to enable resource savings, which allows efficiently investing in the development of modern machinery and technology as well as launching production of innovative products. Interior details are displayed as an example of industrial building conversion into a preschool educational facility.

The purpose of the study is to improve the techniques of enhancing the bearing capacity of reinforced concrete columns by using composite materials and reducing related labor inputs. To this end, it is suggested that removable or permanent formwork systems be replaced with a jacketing formwork combining the benefits of both removable formworks (quick turnaround, adaptability due to the use of high-strength and light-weight composites) and stay-in-place formworks (the factory-made decking forms part of the column to be reinforced and does not require extra finishing). The paper argues that a jacketing formwork is multifunctional, as it performs the protective function in addition to the molding one, and provides the description and schematic design featuring two formwork options. The use of jacketing formworks allows reducing labor inputs when reinforcing columns and restoring their geometric dimensions, thus cutting down on the overall reconstruction time.

A conclusion is made that the use of modern composite materials for manufacturing jacketing formworks allows not only making or reinforcing rectangular-section columns, but also changing the geometric configuration of the cross section for reconstruction purposes.

Keywords: reconstruction, conversion, jacketing formwork, adaptability, lightweight, multi-functionality, reducing labor inputs

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1. INTRODUCTION

Reconstruction is one of the principal approaches to extending the lifecycle of real property, due to which the past fifteen years (especially from 2010 to 2020) have seen not only an increase in the amount of reconstruction activities [1, 2], but also the development of innovative technologies ensuring energy efficiency of reconstruction efforts [3-5]. Among innovative technologies used for reconstruction of industrial buildings there are digital technologies as well [6, 7]. In the work [8], the authors note that the feasibility of adapting an enterprise to meet the challenge of changing requirements is becoming increasingly important under the current manufacturing conditions, such as in Industry 4.0 scenarios. A virtual built-in model of an enterprise and the adjacent workshop building provides a meaningful support for decision-making and the relevant information for digital twins, in particular, to track their entire service life and plan repair and reconstruction works based on manufacturing simulation.

It was established that the use of construction innovations for reconstruction of buildings and facilities helps improve their architectural and engineering solutions, enhance their operational reliability and economic efficiency, etc.

As the global practice of converting industrial buildings has shown, this is a complex managerial task [9], but resolving this task ensures competitiveness of the related services, thereby setting up the new market conditions. The freeing up of land plots where all process operations are arranged enables cost savings, for example, by putting aside or renting out such areas. In the work [10], special attention is paid to the issues of reorganization of industrial territories, which, as noted, can foster an efficient development of such territories and their successful functional adaptation on the contemporary stage.

According to the research [11], there is a number of rationales for conservation of industrial facilities. To such rationales, the author of the paper holds, belong, first of all, a largely acceptable condition of load-bearing structures, and second, the beneficial spatial layout characteristics of industrial facilities, useful in terms of forming a new function, in particular, that of residential property (such as, for instance, free layout, good insolation, and often fairly attractive views out the window).

There are other considerations proving the benefits of reconstruction over new industrial building construction. In the case of new enterprise construction, the cost of construction and installation works accounts for 70% of all capital expenditures, in the case of enterprise expansion – for about 60%, while in the case of reconstruction – for some 26% thereof. Such conservation of material resources allows efficiently investing in the development of state-of-the-art machinery and technology and launching production of innovative products. The payoff period for the investment in reconstruction is 2-2.5 times shorter and the total cost per unit of manufacturing capacity is on average 30% lower than for new construction. It is worth noting that reconstruction works are normally 25…30% and sometimes 50…100% more labor intensive than new construction. Still, the overall time expenditure during reconstruction is 1.5-2 times lower.

It is known that altering the spatial layout solutions as part of reconstruction is accompanied by replacement or demolition of certain structural elements, where a part of their materials is due for return and the other part, once recycled, can conveniently be used both for new construction and for reconstruction purposes. In the scientific study [12], it is observed that "the making of concretes with a complete replacement of the natural filler with fillers obtained by the recycling of used concrete products yields a high-quality concrete." The paper underlines the economic and environmental efficiency of the use of a filler manufactured from demolished concrete structures. The obtaining of fillers by way of recycling concrete scrap is also explored in another study [13-15].

Although the better part of industrial reconstruction projects are aimed at altering the spatial layout solutions and improving the operational characteristics without changing the functional purpose of industrial buildings and facilities, there are successful examples of reconstruction of obsolete industrial buildings involving functional repurposing – in that they were turned into residential, administrative, educational, cultural or art facilities.

Industrial building reconstruction involving functional repurposing and subsequent reorganization of former industrial buildings is on the rise in many countries of Western and Eastern Europe, some US states, some provinces of Canada, China, Japan, Singapore, Korea, etc. After reconstruction, the antique industrial facilities in many largest cities around the world dating back to the eighteenth and nineteenth centuries have become the centers of industrial tourism. Russia also has wide-ranging experience of reconstruction of industrial facilities and reorganization of former industrial territories aimed at industrial legacy conservation. This is true not only for Russia's two national capitals, but also for its major regional clusters.

2. METHODS AND MATERIALS

This research focuses on the reconstruction of industrial buildings designed for their conversion into preschool educational facilities, which, similarly to residential property, are in high demand.

Fig. 1 shows examples of industrial reconstruction efforts undertaken in other countries to convert industrial facilities into residential and public buildings.

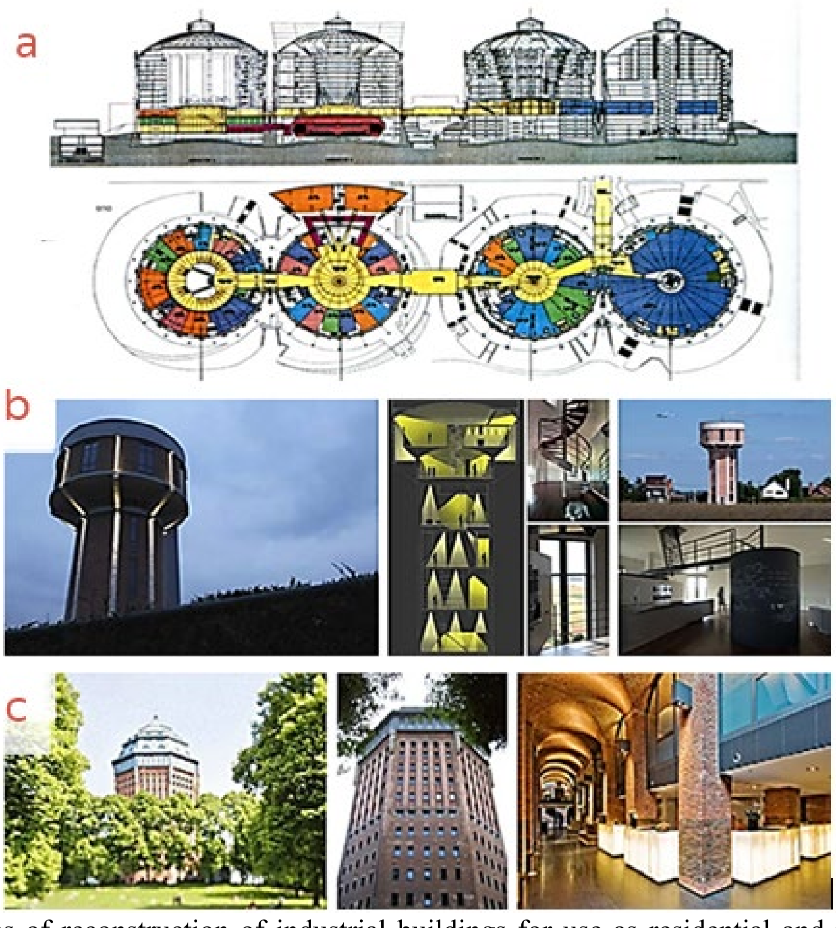

Fig. 1. Examples of reconstruction of industrial buildings for use as residential and public building stock: a – reconstruction of gas holders to form a multifunctional complex including a cinema hall, concert hall, municipal archive, dormitory, school, and kindergarten (Vienna, Austria); b – reconstruction of a water tower as a seven-story residential building with multilevel apartments (Brussels, Belgium); c – reconstruction of a water tower as a hotel (Hamburg, Germany) [11].

Reconstruction is known to involve the replacement, reinforcement and restoration of structural elements regardless of the type of facility being reconstructed. Taken together, this results in extending the residual useful life and improving the functional reliability of a construction system.

The purpose of this paper is to improve the reinforced concrete column strengthening techniques based on the use of composite materials. For this purpose, the key construction technologies that help reduce labor inputs have been identified by reviewing the foreign and domestic studies in the field.

That said, the reinforcement of structural elements of construction systems, including columns, requires enlarging the cross-section with various methods, where the use of stay-in-place formwork systems proves the most effective solution as it meets the labor input reduction requirements [16-18], and as such, provides improved turnaround rates. It should be noted that the authors of the publications [16-18], as well as [19-21] underscore that stand-in-place formworks made of composite materials, especially construction materials, are expected to be more in demand considering that they are strong, lightweight and fire-safe.

Jacketing formworks are high technology forms used to reinforce columns as part of building reconstruction. The authors [22] suggest a jacketing formwork made of U-shaped composite components to be assembled by two fitters after having restored the initial geometric dimensions of the columns where needed. In the publication, the authors provide a comparison chart of labor inputs applicable for the suggested formwork, both with the previously developed and conventional small-section forms. Because a jacketing formwork makes part of a restored column (as the column's permanent element), it proves economical in practical application due to the following reasons: it eliminates the form disassembly work while the jacket itself makes for a surface fully prepared for the finishing of the structural element.

In the publication [23], the authors discuss an improved prefabricated forming system made also of composite materials, which can be used both in making new columns and in reinforcing the existing ones. Since the decking (facing) contacting the concrete surface is made of artificial porous wood having an ideally smooth surface, the finishing works require marginal material and labor inputs. The formwork design is shown in Fig. 2.

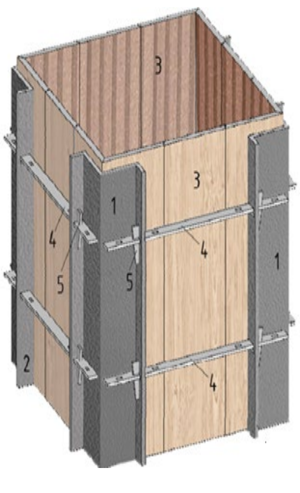

Fig. 2. Formwork system design: 1 – high-strength plastic angle forming the framework basis; 2 – free lengths of angles; 3 – deck made of artificial porous wood; 4 – clamps; 5 – wedge joints [23].

The main framework elements are angles (L-shaped items) made of high-strength plastic and having special outlets with holes provided to fit in clamps connecting the angles and secure clamps with wedge inserts. The advantage of the suggested formworking system is the capacity for increasing and reducing the deck width to accommodate the cross-section of a new or reinforced column with the appropriate dimensions as the deck is made up of segregated matchboards. This allows improving the formwork turnaround.

3. RESULTS AND DISCUSSION

The high strength and lightweight of modern composite materials, in particular, plastics and artificial porous wood, enable their use for manufacturing not only high-technology forming structures, but also supporting elements – jackets. Normally, the term “jacket” as applied to forming systems is employed in the design and development of stay-in-place formworking structures [24, 25]. When used on the website [26], a jacket is understood as a protective coating of the formwork facing directly contacting the concrete mixture.

Due to the emergence of innovative materials on the market and their adoption for the manufacture of efficient forming systems and the enhancement of cast-in-situ construction technologies, the traditional definition of a forming system fails to fully describe the functional purpose of a formwork. For example, stay-in-place formworks making part of a load-bearing structural element cannot be considered an auxiliary or temporary structure. During reconstruction of construction systems, including in the case of conversion aimed at reducing labor inputs, structural elements can be brought up to size using among others ready-made modular elements; in this case, a formwork is not only a forming structure used to obtain the necessary geometric dimensions or shapes, it also serves to secure the set dimensions and shapes and protect the structural elements against environmental factors up to the commissioning phase. Here it appears fitting to use the term “jacketing formwork”. A jacketing formwork must be lightweight, easily adaptable and capable of ensuring enhanced turnaround.

Fig. 3 shows the interior details of a preschool educational facility converted from an industrial facility.

Fig. 3. Interior details of a preschool educational facility converted from an industrial facility (creative design by Akopyan G.O.).

To improve the load bearing capacity of columns, the cross-section area is enlarged with the help of shop fabricated modular panels with a thickness assumed according to the design calculation. Such modular panels do not require onsite finishing because they are supplied ready-to-use and wrapped in a protective film to preserve their visual appearance. Before the protective film is applied, the rear side of a modular panel is treated with special adhesive compounds and the outer side is additionally covered with multilayer protective screens made of polyurethane foam.

This type modular panels, when used in making new columns, serve as the facing (decking) of the forming system (fig. 4, a 1, b 1), i.e. they are multifunctional, capable of bearing great loads and, as practice abroad shows, mostly made of fibercrete.

Fig. 4 shows the details of assembly of two types of jacketing formworks consisting of L-shaped and U-shaped components made of impact-resistant plastic. The jacketing formwork model is also discussed in the scientific publication [23]. The jacketing formwork components are interconnected using suitable joints available on the construction market.

Tables 1 and 2 below set out the labor inputs for the main and auxiliary processes involved in making new columns and reinforcing existing columns with a height of 3 meters and a section area of 500×500mm during reconstruction by way of repurposing construction systems. The labor inputs in parentheses apply in the case of a jacketing formwork made of two U-shaped components.

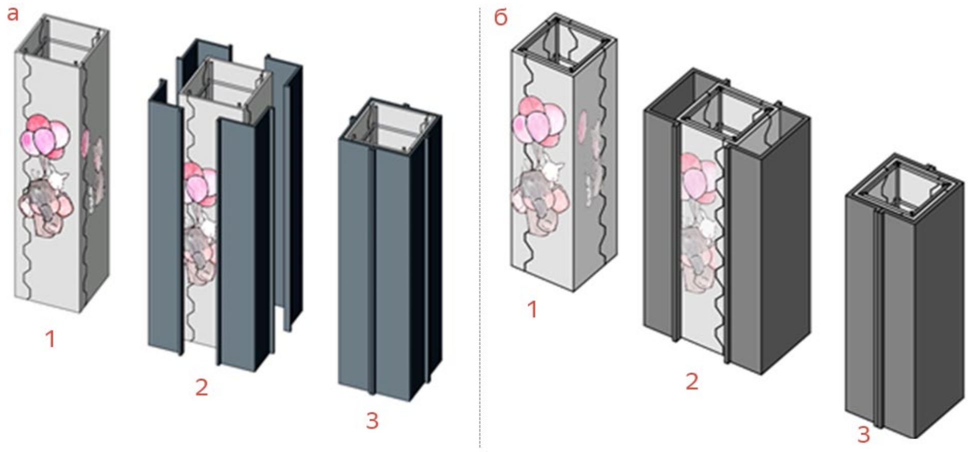

Fig. 4. Details of a jacketing formwork assembly: a – formwork made of L-shaped components: 1 – modular panels (formwork boards), 2 – four L-shaped components, 3 – jacketing formwork as assembled; b – formwork made of two U-shaped components: 1 – modular panels (formwork boards), 2 – two U-shaped components, 3 – jacketing formwork as assembled (developed by the authors).

Table 1. Labor inputs involved in the main and auxiliary processes of jacketing formwork assembly/disassembly and concreting in making new columns (developed by the authors), man-hours.

Process description	Labor inputs, man/hour
Mounting the reinforcing cage in the design position	0.36
Mounting the locks on rebar to provide a protective concrete layer	2.8
Removing the protective film from the rear side of the modular panels	0.68
Mounting and securing (installing) the modular panels in the design position	2.7
Installing the jacketing formwork	0.78 (0.41)
Concreting the column	1.13
Dismantling the jacketing formwork	0.24 (0.15)
Removing the protective screen and protective film from the outer side of modular panels	0.39
Total	9.08 (8.62)

Table 2. Labor inputs involved in the main and auxiliary processes of strengthening the existing reinforced concrete columns (developed by the authors), man-hours.

Process description	Labor inputs, man/hour	
	Option 1	Option 2
Removing the weakened concrete areas	1.12	-
Clearing dirt from the columns to be installed	1.74	1.74
Welding short pieces with bare bars	1.4	-
Removing the protective film from the rear side of the modular panels	0.68	0.68
Mounting and securing (installing) the modular panels in the design position	2.7	2.7
Installing the jacketing formwork	0.78 (0.41)	0.78 (0.41)
Dismantling the jacketing formwork	0.24 (0.15)	0.24 (0.15)
Removing the protective screen and protective film from the outer side of modular panels	0.39	0.39
Total	9.05 (8.59)	6.53(6.07)

The labor inputs provided in Tables 1 and 2 are determined in accordance with the effective regulatory documents and practical experience.

The protective film on the outer side of modular panels is removed after the completion of all finishing works on the reconstructed facility.

The comparison of labor inputs involved in competing a single column with the dimensions of 500 × 500 × 3000 mm using the suggested technology with two types of jacketing formwork is based on the final values given in Table 1 (Fig. 5).

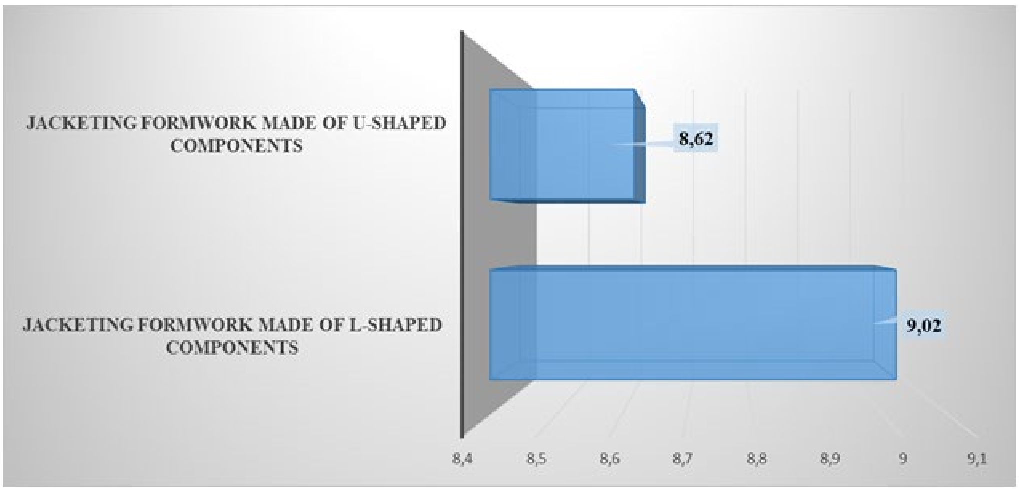

Fig. 5. Labor inputs involved in making a single column with the dimensions of 5500 × 500 × 3000 mm using jacketing formworks with L-shaped and U-shaped components (developed by the authors), man-hours.

The diagram based on the final values given in Table 2 (Fig. 6) shows that the labor inputs are lower when the column reinforcement is accomplished by using a jacketing formwork made of U-shaped components.

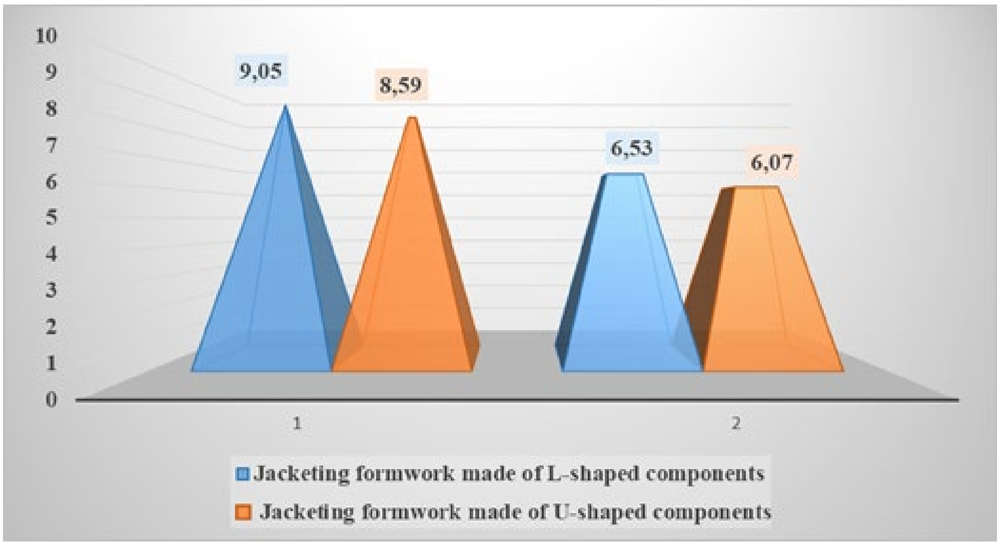

Fig. 6. Labor inputs involved in strengthening a column with the dimensions of 500 × 500 × 3000 mm using jacketing formworks with L-shaped and U-shaped components: 1 – strengthening with removing weak concrete stretches and welding short pieces with bare bars, 2 – strengthening without removing weak concrete stretches and without welding short pieces with bare bars (developed by the authors), man-hours.

Because the reconstruction of buildings and facilities involves the making and reinforcing of a considerable number of load-bearing structural elements, including columns, this results in a reduced overall work time. A second factor contributing to a reduction of the work duration is the elimination of finishing works since the column finishing on the construction site is not needed because modular panels are supplied fully prefabricated.

Let us consider the effectiveness of jacketing formworks in terms of installation and dismantling labor inputs in man-hours per sq. m during column reinforcement. The chart (Fig. 7) provides the data for the previously developed forming systems and conventional cast-in-situ formworks designed in particular for strengthening columns [23], as well as the data obtained as part of this study.

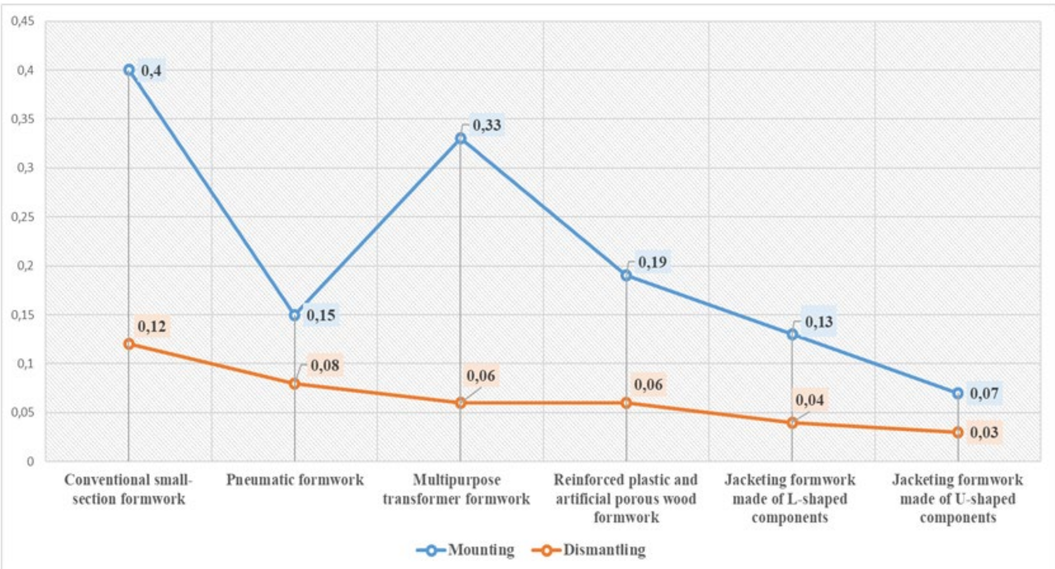

Fig. 7. Comparison of labor inputs involved in the installation and dismantling of various formwork systems designed for column reinforcement (developed by the authors based on the [23] data and the data obtained in the course of this study), man-hours/m^2.

The analysis of the chart values shows that the use of jacketing formworks is most effective as the installation and dismantling operations are accomplished with the lowest labor expenditure.

The use of modern composite materials to make jacketing formworks that include a jacket having the protective function and modular panels forming the decking (facing), where such forming function allows not only making and reinforcing square-section columns, but also changing the cross section's geometric configuration for reconstruction purposes, is undoubtedly highly relevant today.

4. CONCLUSIONS

One of the principal approaches, which helps reduce labor inputs involved in reinforcing or making structural columns during building reconstruction, is the use of high-technology formworking structures. Due to the adoption of modern composite materials for making formworks, the resulting formworking structures are characterized by lightweight and high turnaround rates, which eventually ensures their enhanced adaptability in practical applications.

The traditional definition of a formworking system does not fully describe the essence of this structure. Modern formworking systems are more than just temporary auxiliary forming features and intended not only to obtain the set dimensions of future structural elements of buildings and facilities. Being part of load-bearing structural elements, stay-in-place formworks (including lightweight and high technology forms) become permanent forming structures that reliably secure the necessary design dimensions.

The jacketing formwork suggested here partially serves as a stay-in-place formwork because shop-fabricated modular panels used as the decking form part of a structural column, and the cage (jacket) becomes a reusable part of a forming structure. Apart from multiple use, a jacketing formwork is distinguished by lightweight and high adaptability as was experimentally proven. It is also multifunctional for, in addition to the forming function, it also performs the protective function. Because shop-fabricated modular panels (decks) are supplied fully shop-finished, a jacketing formwork ensures preservation of the visual appearance of the reinforced or newly made columns protecting them against external mechanical impacts. The use of shop-finished modular panels avoids the need for finishing works on the construction site, thus reducing the overall duration of the work.

The use of modern composite materials to make jacketing formworks allows not only making and reinforcing square-section columns, but also changing the geometric cross section configuration during reconstruction.

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